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Effects of a Waste Paper Product on Soil Phosphorus, Carbon, and Bulk Density

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ABSTRACT

Applications of manures to agricultural fields have increased soil test values for P to high levels in parts of the USA and thus increased the likelihood that P will be transported to surface water and degrade its quality. Waste paper applications to soils with high STP (soil test P) may decrease the risk of P transport to surface water by decreasing DRP (dissolved reactive P) by the formation of insoluble Al–P complexes and providing organic matter to improve infiltration. A field experiment was conducted near Booneville, AR (USA) to assess the effects of different rates of a waste paper product addition on STP, soil bulk density, and total soil C with a soil with approximately 45 mg Bray1-P kg^{-1} soil (dry weight). A Leadvale silt loam soil (fine-silty, siliceous, thermic Typic Fragiudult) was amended with 0, 22, 44, or 88 Mg waste paper product ha^{-1} to supply approximately 90, 170, or 350 kg Al ha^{-1}, respectively. One year after additions, there was a strong negative correlation between waste paper product application rates and soil bulk density, and a strong positive correlation between rates and total soil C content. Soil bulk density and total C 2 yr after additions, and soil DRP and Bray1-P were not affected by waste paper additions. These results support the hypothesis that decreases in DRP in runoff from soils receiving waste paper additions were probably due to changes in soil organic matter and bulk density, rather than changes in the chemical forms of soil P.

Environmental concerns arising from land application of manures are leaching and runoff losses of P to ground and surface water (Sims et al., 1998). Concentrated animal feeding operations create enormous amounts of animal manure. In most instances, these manures are applied to agricultural fields located near the feeding operation. Long-term applications of animal manures to agricultural land have resulted in high STP levels. For example, Mehlich III extractant soil tests in 1999 showed that >60% of soil samples from counties in Arkansas with high-intensity poultry production had high STP and >30% were very high (DeLong et al., 2000).

New technologies are needed to minimize the risk of P transport from soils with high STP to ground and surface water. One approach may involve the use of soil amendments. In certain instances, gypsum additions have been effective of reducing the loss of DRP in runoff from fields with high STP (Stout et al., 1998). The chief mechanism by which gypsum reduces DRP is by promoting the aggregation of soil particles, thus reducing the amount of P transported along with sediment in runoff (McCray and Sumner, 1990). It is possible that reduction in P losses also resulted from the formation of relatively insoluble Ca phosphate complexes when Ca from gypsum reacts with soluble phosphate. Gypsum can reduce DRP, even when STP is very high, if enough Ca is added. Three annual additions of 5.0 Mg gypsum ha^{-1} decreased soil DRP in a thermic Udertic Paleustalf soil in Texas with Bray1-P values that approached 4000 mg P kg^{-1} (Brauer et al., 2005); however, three annual applications of 1.5 Mg gypsum ha^{-1} had no effect (Brauer et al., 2005). The higher rate of gypsum application added 3500 kg Ca ha^{-1}, compared with 1000 kg Ca ha^{-1} for the lower rate. Gypsum applications had no effect on Bray1-P values.

Another soil amendment that can reduce soil DRP is alum (Moore et al., 1999). The chief mechanism by which alum reduces DRP losses is by immobilization of readily soluble P by the formation of relatively insoluble complexes between soil P and the added Al. Alum added to litter or as a soil amendment reduces DRP and thus reduces the likelihood that the P will be transported from agricultural land to surface water.

It may be possible to add Al to soils to complex readily soluble P by adding a waste paper product. Waste paper contains significant quantities of Al, with levels routinely exceeding 3 g kg^{-1} dry weight (Edwards et al., 1995). Aluminum was released into the soil solution when an amendment produced from waste paper and anhydrous NH_4 (C/N ratio of 30:1) was added to soil (Edwards et al., 1995; Edwards, 1997; Lu et al., 1995, 1997). In these four studies, waste paper was added at 2 kg C m^{-2}, which corresponds to ~50 Mg waste paper ha^{-1}. When this waste paper amendment was added to soils, N, Ca, Mg, and P foliar deficiency symptoms of corn seedlings were observed (Lu et al., 1995). These researchers hypothesized that plants growing in amended soils were P deficient as a result of the precipitation of P from the soil solution by Al. To overcome this problem, P was added to a weed control mulch product developed from recycled paper to reduce the toxic effects of Al (Smith et al., 1997; 1998).

Therefore, it may be possible to use a soil amendment made from waste paper as a source of Al to reduce soil DRP. Results from a preliminary study indicated that the amount of P in runoff from a simulated rainfall on a thermic Udertic Paleustalf soil in Texas with Bray1-P values approaching 4000 mg P kg^{-1} was reduced 1 mo after incorporation of a waste paper product (Livingston et al., 2002); however, Brauer et al. (2005) found no significant reductions in either soil Bray1-P or DRP 4 mo after waste paper addition. The amount of waste

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Abbreviations: DRP, dissolved reactive P; LSSE, least square standard errors; MSS, mean sum of squares; STP, soil test P.

Table 1. Selected soil chemical characteristics (0–10cm) of the experimental area before establishment of the experiment. Data are means plus or minus the standard error of the means (n = 16).

Soil property	Test 1	Test 2
Soil pH	6.6 ± 0.1	6.6 ± 0.1
Bray1-P, mg P kg^{-1} soil	64 ± 3	29 ± 2
Dissolved reactive P, mg P kg^{-1} soil	6.5 ± 0.3	2.6 ± 0.2
Total C, g C kg^{-1} soil	3.1 ± 0.1	3.1 ± 0.1

paper added annually was the same in both studies and supplied ~100 kg Al ha^{-1}, only a fraction of the Bray1-P values. Therefore, Brauer et al. (2005) hypothesized that insufficient Al had been added to react with extractable P that may become available to the DRP pool and some other factor was responsible for the observed decrease in P in runoff. Pote et al. (1999) demonstrated that the DRP in runoff was greatest when runoff volumes were greatest, i.e., when infiltration of rainfall was least. Addition of organic matter, such as from a waste paper product, results in decreased soil bulk density, which in turn is associated with greater rates of rain infiltration (Sarrantonio et al., 1996). Therefore, decreases in DRP in runoff with waste paper additions, observed by Livingston et al. (2002), could have resulted from decreases in bulk density of the soil and increases in water infiltration. The objectives of study were to determine the effects of the addition of a waste paper product on soil bulk density, total soil C, soil Bray1-P, and DRP using a soil with moderate STP.

MATERIALS AND METHODS

The experiment was conducted on a Leadvale silt loam ~10 km southwest of Booneville, AR (35° 05.133′ N; 93° 59.511′ W). Leadvale series soils are moderately well drained and formed on nearly level or gently sloping landscape positions in loamy sediments from weathered sandstone and shale. The Ap horizon is ~15 cm in depth. These soils are low in natural fertility. Water permeability is moderately slow due to the presence of a firm, brittle layer in the subsoil. The mean elevation is ~150 m above mean sea level. Average daily maximum temperatures range from a minimum of 10°C in January to a maximum of 34°C in July and August. Average annual rainfall totals ~1060 mm, but soil moisture deficiencies usually occur in August and September due to high air temperatures and low precipitation. For the 3 yr before the experiment, the field was double-cropped with soybean [*Glycine max* (L.) Merr.] and wheat (*Triticum aestivum* L.), which were used as green manure crops. Soil samples were collected from the top 0 to 15 cm in May 2002 and analyses revealed low Bray1-P values, ranging between 15 and 30 mg P kg^{-1} soil (data not shown). Therefore, triple superphosphate to supply about 160 kg P ha^{-1} was surface applied and then incorporated into the top 25 cm by disking in June 2002. No crops were planted in the experimental area after May 2002.

The experimental design consisted of two experiments, each with four replications of four rates of waste paper product addition (0, 22, 44, or 88 Mg ha^{-1}). The waste paper product was produced by Tascon (Houston, TX) and had an average Al content of 4 g kg^{-1}. Thus, the three waste paper application rates supplied approximately 90, 170, or 350 kg of Al ha^{-1}, respectively. Plots measured 2 by 2 m and were separated by a 0.6-m border. Tests 1 and 2 were started in early September 2002 and late August 2003, respectively. A 3-m border separated the two tests. The waste paper product was incorporated into the top 15 cm of soil with a rototiller. Plots receiving no waste paper product were similarly rototilled. After incorporation, the soil surface of plots was covered with a landscape mat to reduce weed seedling emergence. Weeds in the border area were controlled with glyphosate [*N*-(phosphonomethyl) glycine] applications. Traffic (both human and equipment) on the plot area was prevented.

Soil samples (0–10 cm) were collected the week before waste paper product application, in August the year after waste paper applications in both tests, and in the second year for Test 1. Soil bulk density (0–10 cm) was determined as described by Sarrantonio et al. (1996). Soil from the bulk density determinations was then air dried and ground to pass a 2-mm sieve. Soil samples were analyzed for pH (Peech, 1965) and Bray1-P (Olsen and Sommers, 1982). Soil DRP was measured using an extract/soil ratio of 25 mL of distilled water to 1 g dry soil (Self-Davis et al., 2000). Pote et al. (1996) demonstrated that values for DRP extracted using 25 mL of extractant to 1 g of dry soil were better correlated with DRP content of runoff than other soil test parameters. Phosphorus in Bray1 and water extracts was determined colorimetrically (Murphy and Riley, 1962). The Agricultural Diagnostic Laboratory, University of Arkansas (Fayetteville, AR) determined total soil C by combustion with LECO CN2000 instrument. All soil test values are expressed on a dry-weight basis.

Data were subjected to analysis of variance using PROC GLM (SAS Institute, 1999). Data from 1 yr after soil amendment application were analyzed using a model consisting of the two tests as main plots and the four waste paper product rates as subplots. As such, the error term for testing significance of effects of tests was the test × replication interaction (df = 6). The residual error term (df = 24) was used to test the significance of the effects of waste paper product rates and rates × test interaction. Data from Test 1 were also analyzed using a

Table 2. Summary of the analysis of variance examining the effects of test and WPR (waste paper product rate) on selected soil properties (0–10 cm) 1 yr after application. These results summarize analyses of data collected 1 yr after application of waste paper product from two tests.

		Soil property			
Source of error	df	Soil bulk density	Bray1-P	DRP†	Total C
		mean sum of squares			
Test	1	0.18911***	3670.8**	64.128**	0.32663
Test × Replication	6	0.00114	125.4	2.945	0.10507
WPR	3	0.04339***	162.57*	0.2828	0.78323***
Residual error	18	0.00310	37.44	1.0060	0.07581

* Indicates that F-value is significant at 0.05 probability level.
** Indicates that F-value is significant at 0.01 probability level.
*** Indicates that F-value is significant at 0.001 probability level.
† DRP = dissolved reactive P.

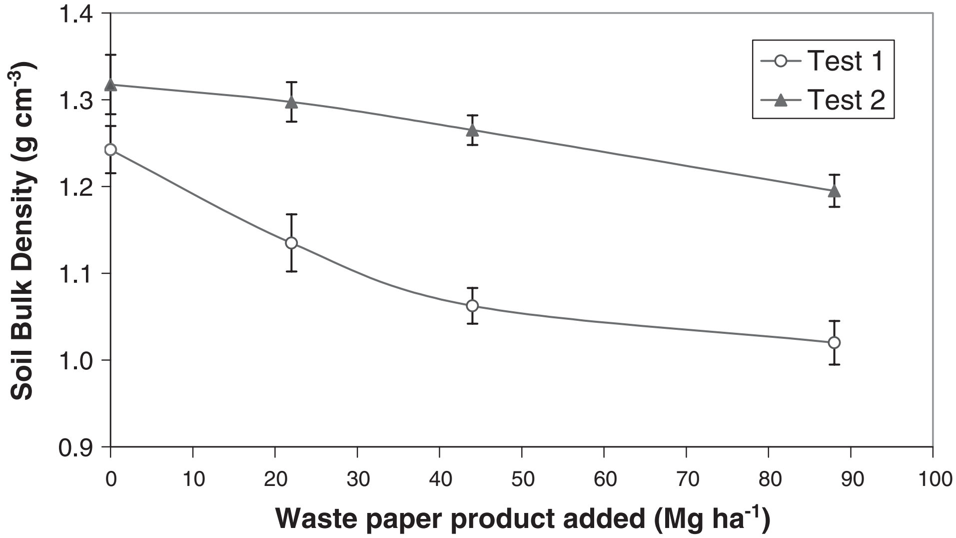

Fig. 1. Effects of rate of waste paper addition on soil bulk density (0–10 cm) 1 yr after waste paper incorporation. Data are means from two tests, each with four replications. Bars denote least squares standard errors.

model consisting of 3 yr (i.e., before addition, and 1 and 2 yr after additions), four waste paper rates, and four replications as main effects. In these analyses, waste paper product rates were treated as main plots and years as subplots. Accordingly, the error term for testing significance of effects of years and water paper product rates was the rate $\times$ replication interaction (df = 9) and the residual error term (df = 12 or 24 if years = 2 or 3, respectively) was used to test the significance of years and year $\times$ rate interaction. Least significance difference was used to test the effects of main plots at $\alpha = 0.05$. Data reported herein are least square means plus or minus the least square standard errors (LSSE).

RESULTS

Effects One Year after Addition

Selected soil chemical characteristics of samples collected just before establishment of plots are reported in Table 1. Average values for soil pH and total C were the same for samples from Tests 1 and 2; however, average values for soil Bray1-P and DRP were greater for samples from Test 1 than for samples from Test 2. These differences in STP values may indicate that Test 2 was located beyond the area that received P fertilization in 2002.

Soil bulk density, soil DRP, and Bray1-P 1 yr after waste paper product application were affected by test (Table 2). Both soil DRP and Bray1-P values were greater in Test 1 than Test 2. Soil DRP averaged 6.0 and 3.1 mg P kg^{-1} with LSD of 1.5 and Bray1-P averaged 49 and 28 mg P kg^{-1} with LSD of 10 for Tests 1 and 2, respectively. Average soil bulk density 1 yr after waste paper product application was lower in Test 1 than Test 2, 1.12 vs. 1.27 g cm^{-3} with LSD of 0.03.

Addition of the waste paper product had significant effects on soil bulk density, Bray1-P, and total C 1 yr later (Table 2), but no effect on soil DRP values. Soil bulk density 1 yr after application decreased with increasing rates of waste paper product in both tests (Fig. 1). In Test 1, soil bulk density declined from 1.24 $\pm$ 0.02 to 1.02 $\pm$ 0.02 g cm^{-3} 1 yr after the incorporation of 88 Mg waste paper product ha^{-1}. In Test 2, soil bulk density declined from 1.32 to 1.20 $\pm$ 0.02 g cm^{-3} 1 yr after application of 88 Mg waste paper product ha^{-1} (Fig. 2). Soil total C increased 1 yr after application with increasing rates of waste paper product in both tests. Soil total C values between the two tests were similar. Soil total C increased from ~23 to 28 g C kg^{-1} soil 1 yr after application of 88 Mg waste paper product ha^{-1} (Fig. 2).

There was a progressive increase in Bray1-P values with increasing waste paper product addition. In Test 1, Bray1-P values averaged 42 $\pm$ 3 (LSSE) mg P kg^{-1} in the absence of waste paper product addition 1 yr after establishing plots. The addition of 22, 44, and 88 Mg waste paper product ha^{-1} increased Bray1-P values to 45, 54, and 57 mg P kg^{-1} (LSSE = 3), respectively, 1 yr after application in Test 1. In Test 2, Bray1-P values averaged 26 $\pm$ 1 (LSSE) mg P kg^{-1} in the absence of waste paper product addition 1 yr after establishing plots. The addition of 22, 44, and 88 Mg waste paper product ha^{-1} increased Bray1-P values to 27, 28, and 30 mg P kg^{-1} (LSSE = 1), respectively, 1 yr after ap-

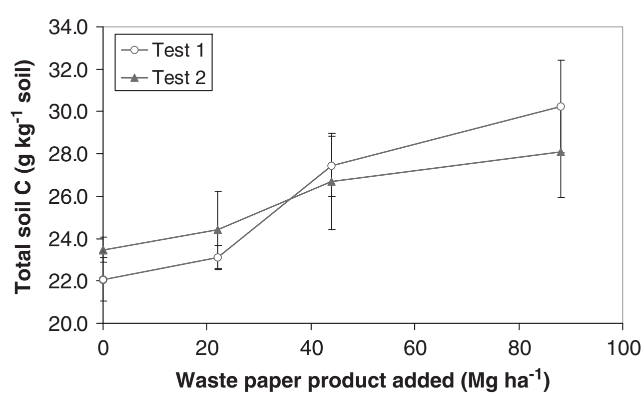

Fig. 2. Effects of rate of waste paper addition on total soil C (0–10 cm) 1 yr after waste paper incorporation. Data are means from two tests, each with four replications. Bars denote least squares standard errors.

Table 3. Summary of the analysis of variance examining the effects of years after application and WPR (waste paper product rates) on selected soil properties (0–10 cm). These results summarize analyses conducted on data collected from Test 1.

Source of error	df	Soil bulk density	df	Soil property DRP†	Bray1-P	Total C
		MSS†		MSS†		
WPR†	3	0.0220*	3	1.385	178.6	0.2505*
WPR × Replicate	9	0.0053	9	2.579	239.5	0.0286
Year	1	0.2129***	2	3.490	1935.9***	0.8525***
WPR × Year	3	0.0189*	6	1.820	76.7	0.3122***
Residual	12	0.0043	24	1.833	30.7	0.0479

* Indicates that *F*-value is significant at 0.05 probability level.
*** Indicates that *F*-value is significant at 0.001 probability level.
† DRP = dissolved reactive P; MSS = mean sum of squares; WPR = waste paper product rate.

plication in Test 2. Soil DRP values averaged 6.0 and 3.1 ± 0.4 (LSSE) mg P kg^{-1} 1 yr after waste paper product application for Tests 1 and 2, respectively, independent of the rate of addition.

There was no significant effect of the waste paper product rate × test interaction on soil bulk density, DRP, Bray1-P, or total C (Table 2). Therefore, the difference in STP between Tests 1 and 2 did not affect the responses of these soil characteristics to waste paper product application.

Effects with Time in Test One

Soil bulk density and total C were found to have been significantly affected by rates of waste paper product addition when the data from Test 1 were analyzed (Table 3). Soil bulk density and total soil C were significantly affected by year and the year × waste paper product rate interaction, while Bray1-P values were only affected by year (Table 3). Bray1-P values were highest just before the addition of waste paper product treatments in 2002 and averaged 64 mg P kg^{-1} soil, compared with averages of 49 and 42 mg P kg^{-1} soil in 2003 and 2004, respectively. Soil DRP concentrations were not affected by year or waste paper product rate (mean = 4.5 ± 0.5 mg P kg^{-1} soil).

Soil bulk density decreased with increasing additions of waste paper product 1 yr after application (Fig. 3). In Test 1, soil bulk density averaged ~1.24 g cm^{-3} 1 yr after application where no waste paper product had been applied. The addition of 22 Mg waste paper product ha^{-1} decreased soil bulk density to 1.14 g cm^{-3}. Further increases in waste paper product to 88 Mg ha^{-1} decreased soil bulk density to 1.02 g cm^{-3}; however, the effect of the addition of waste paper on soil bulk density had disappeared 2 yr after waste paper product addition in Test 1.

Total soil C increased with increasing rates of waste paper product addition 1 yr after application (Fig. 4). One year after waste paper product application, total soil C increased from ~21 g C kg^{-1} soil to >26 g C kg^{-1} soil where 88 Mg waste paper ha^{-1} had been incorporated. The effect of rate of added waste paper product on total soil C levels was less 2 yr after application. Two years after application, total soil C averaged ~21 g C kg^{-1} soil in the absence of waste paper product incorporation to a maximum just greater than 22 g C kg^{-1} soil with the highest rate of waste paper product addition.

DISCUSSION

These results regarding the effects of waste paper product application on STP were similar to those found previously in an experiment using a thermic Udertic Paleustalf soil in Texas (Brauer et al., 2005). In both studies, the addition of the waste paper product had little effect on STP, i.e., Bray1-P and DRP concentrations were not significantly ($P < 0.05$) changed by waste paper product additions.

It was hypothesized that the lack of an effect of the waste paper product on STP in the previous study (Brauer et al., 2005) resulted from the addition of in-

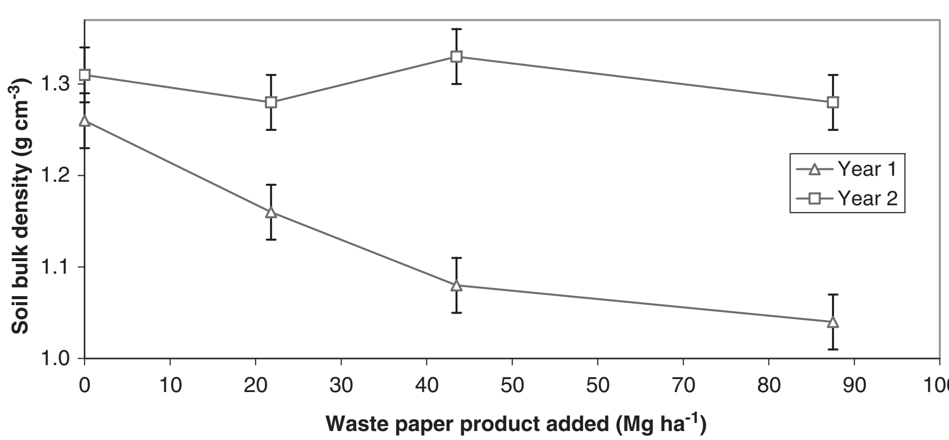

Fig. 3. Effects of rate of waste paper addition and years after application on soil bulk density (0–10 cm). Data are from 1 (□) and 2 yr (△) after waste paper application for Test 1 and are means of four replications. Bars denote least squares standard errors.

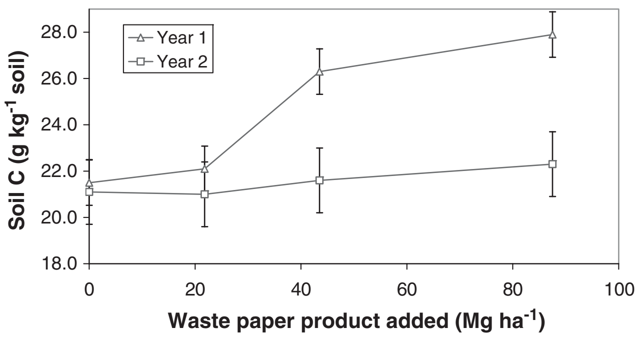

Fig. 4. Effects of rate of waste paper addition and years after application on total soil C (0–10 cm). Data are from 1 (□) and 2 yr (△) after waste paper application for Test 1 and are means of four replications. Bars denote least squares standard errors.

sufficient amounts of Al in the waste paper to react fully with the amount of available soil P. In that study (Brauer et al., 2005), the Bray1-P values approached 4000 mg P kg^{-1}soil and the addition of Al from the waste paper applications during 3 yr was <300 kg Al ha^{-1} or ~150 mg Al kg^{-1} soil (Brauer et al., 2005). Therefore, the amount of added Al was about one-tenth the STP concentration. In the present study, the amount of added Al in the waste paper was significantly greater than that of soil Bray1-P concentrations. The lowest rate of waste paper product application supplied approximately the same amount of Al as the Bray1-P content, or a 1:1 ratio of added Al to Bray1-P content. The ratio of added Al to Bray1-P content was >4:1 for the highest rate of waste paper product application. Therefore, the lack of added Al was probably not a reason for a lack of reduction in STP with waste paper additions in this study. It is possible that, in both studies, the added Al reacted with soil constituents other than P, thus preventing the formation of insoluble Al–P complexes.

These results also demonstrate that the incorporation of the waste paper product significantly decreased soil bulk density and increased total soil C 1 yr after incorporation (Fig. 1 and 2, Table 2). The effects of waste paper rates on soil bulk density and total soil C was less 2 yr after application (Fig. 3 and 4, Table 3). The decrease in total soil C with time was presumably due to mineralization of the added C. Decreases in soil bulk density were associated with increased total soil C (Fig. 1–4), suggesting that changes in total soil C were, at least partially, responsible for changes in bulk density. These results support the hypothesis that decreases in P in runoff from simulated rainfalls after waste paper incorporation (Livingston et al., 2002) are due primarily to changes in soil bulk density and total soil C, rather than changes in the chemistry of soil P.

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